

Water Quality Restoration Activities in the Nashville District

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Abstract

The Nashville District Corps of Engineers (LRN) operates a series of ten multi-purpose water resources projects within the Cumberland River Basin in Kentucky and Tennessee. The system is made up of a series of low-head main-stem navigation projects and high-head tributary storage projects. The navigation projects have evolved over time as navigation requirements and advancements in industry technology have been realized. However, three large dams that were completed in the early 1950s provide 2/3 of the flood control for this system of reservoirs. These projects were designed and constructed during an era when environmental considerations were minimal at best. The lakes impounded by these structures are quite deep (150-200' maximum depth) and are subject to an annual cycle of thermal stratification. Water located deep in the water column becomes very low in dissolved oxygen during the summer and fall months. The intakes for the hydropower turbines at these projects are located deep in the pool corresponding with this intermittent anoxic zone. As a result, dissolved oxygen concentrations fall below the required 6.0 mg/l for a coldwater environment. LRN has completed a series of water quality restoration projects where low-cost turbine venting technology has been retrofitted to 50-year old turbines to improve the oxygen levels in project releases. Turbine pulsing has also been used as a means to improve downstream flow conditions. The benefits resulting from these modifications coupled with revisions to fish harvest regulations has lead to a healthier ecosystem and more productive trout fishery.

Background

The Cumberland River begins at the confluence of the Poor Fork, Clover Fork, and Martins Fork near Harlan, Kentucky. The river flows southwesterly into Tennessee and then arches through Tennessee back into Kentucky where it empties into the Ohio River at Smithland, Kentucky. The Cumberland River has a total drainage area of 17,925 mi² and an average gradient of 1.2 ft/mile. With a total length of 692.8 miles, the Cumberland River is one of the longest and also one of the most regulated rivers in the United States. See Figure 1 for a map of the Cumberland River Basin.

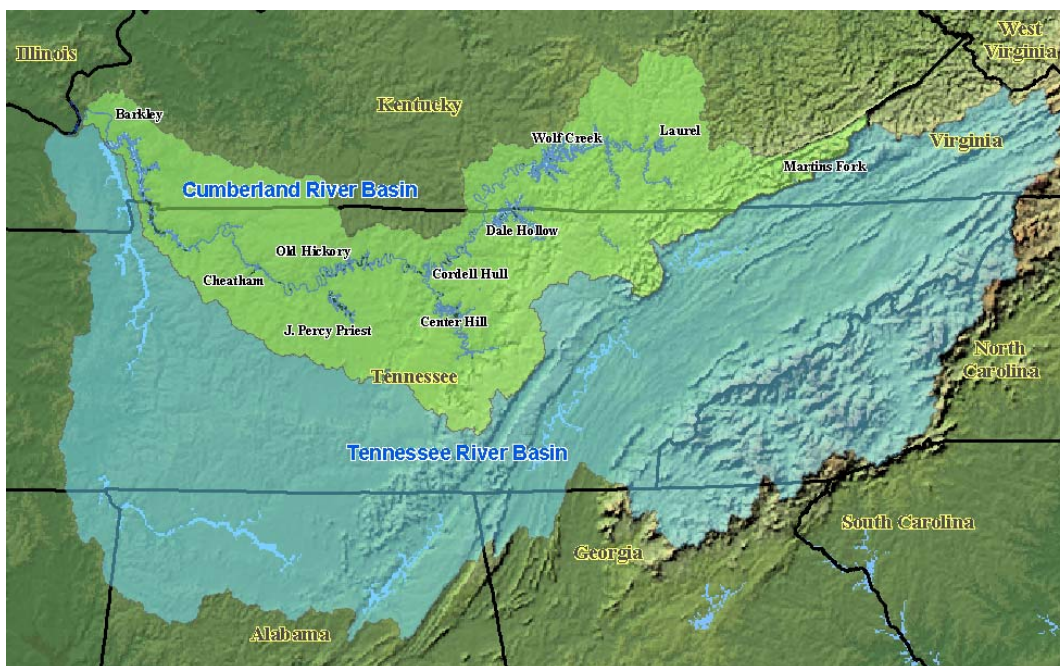


Figure 1. Nashville District Boundary – Cumberland and Tennessee River Basins

LRN operates a system of ten multi-purpose water resources projects in the Cumberland River Basin. See Table 1 for a listing of these projects. Compared to the paralleling Tennessee River, the Cumberland River is longer, has a more braided channel, drains an area less than half in size, and has water of generally higher quality. The Barkley Canal, a one-mile long canal connecting Lake Barkley on the Cumberland River with Kentucky Lake on the Tennessee River, joins the two river systems. The Tennessee and Cumberland Rivers are the two largest tributaries to the Ohio River.

Table 1. Cumberland River Basin Multipurpose Reservoir Data

Project	Location (river mile)	Completion Date	Retention Time (days)
Martins Fork	Martins Fork 15.6	December 1978	21
Laurel	Laurel River 2.3	October 1977	471
Wolf Creek	Cumberland River 460.9	August 1952	140
Dale Hollow	Obey River 7.3	November 1953	343
Cordell Hull	Cumberland River 313.5	February 1974	8
Center Hill	Caney Fork River 26.6	April 1951	131
Old Hickory	Cumberland River 216.2	December 1957	11
Percy Priest	Stones River 6.8	February 1970	95
Cheatham	Cumberland River 148.7	November 1959	2
Barkley	Cumberland River 30.6	March 1966	9

The Cumberland River Basin contains some of the most beautiful and scenic streams

in the country, as emphasized by the large number of state and national parks, forests, and designated wild and scenic rivers. Two major national areas in the upper basin are the Big South Fork National River and Recreation Area in Kentucky and Tennessee and the Daniel Boone National Forest in Kentucky. More than 23 state parks and forests, nine state scenic areas, and 19 wildlife management areas are located in the Cumberland Basin. The U.S. Forest Service operates Land Between the Lakes, a demonstration and recreation area located in the lower basin between the Cumberland and Tennessee Rivers.

Water Quality Conditions

Water quality conditions in the Cumberland River Basin are generally good. However, there are a number of stream segments in both Kentucky and Tennessee that have been listed on the appropriate 303(d) list of impaired streams not meeting state water quality standards. Collectively, these stream segments amount to hundreds of miles of waterways that either don't meet designated stream uses or only partially support those uses. Sources of stream impairment include agricultural activities (sediment and fertilizer runoff), urban runoff (sediment, fertilizer, trash, and petroleum products), resource extraction (coal, oil and gas, logging, and quarry operations), municipal wastewater discharges (nutrients, bacteria, and solids), waste disposal on land (nutrients and bacteria), and hydrologic modification (sediment, excessive algae growth, and oxygen depletion).

Dissolved Oxygen. The water released from LRN projects, in particular water that has passed through the hydropower turbines, is often deficient in its oxygen content. The quality of water within and released from these lakes is at the mercy of water quality conditions in the watershed and the tributary streams. When relatively high levels of nutrients, originating from both point and non-point sources, are exposed to the extended retention times characteristic of Cumberland River Basin impoundments, the resulting oxygen depletion can become severe. Water quality conditions in turbine releases can become critical due to the design of the hydropower system where most of the water released originates from deep in the water column where DO levels tend to be at a minimum. The DO problem is seasonal in nature. Typically, low tailwater DO concentrations are first observed in late spring or early summer and persist until the corresponding lake destratifies in the fall. See Figures 2-5 for plots of observed DO data for hydropower releases from the four major tributary storage projects within the Cumberland Basin. The data points are color coded as follows: green diamonds indicate data collected in the 1970s; blue squares represents data from the 1980s; and red triangles are from the 1990s. These plots illustrate how DO conditions have degraded over time as accompanying watersheds have been subjected to increased non-point source nutrient loads. In addition, there are statistical differences between wet years and dry years with dry years generally resulting in better DO conditions.

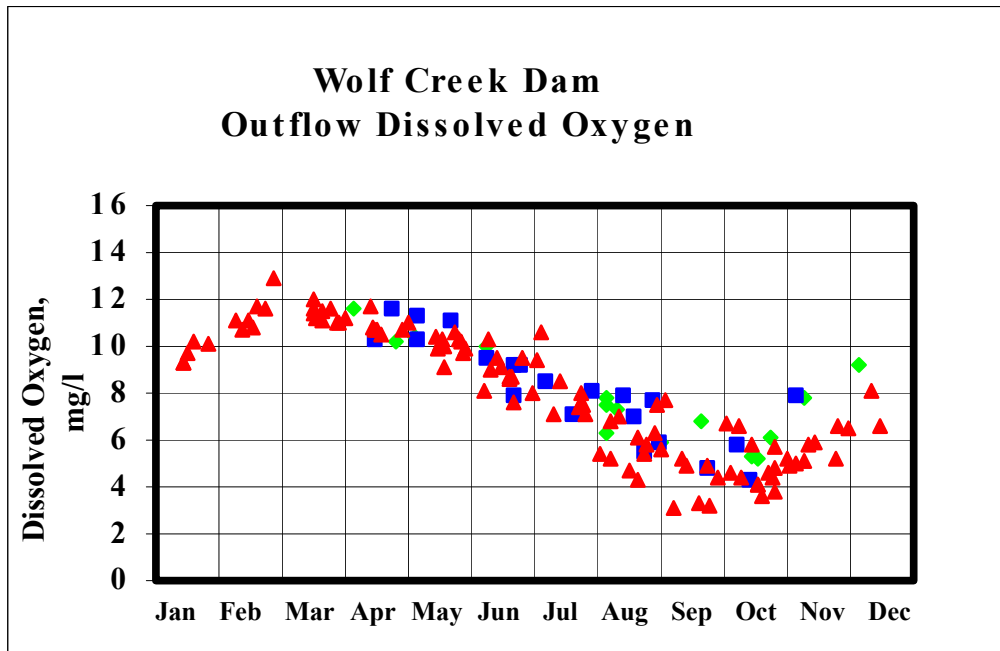


Figure 2. Wolf Creek Dam Outflow Dissolved Oxygen

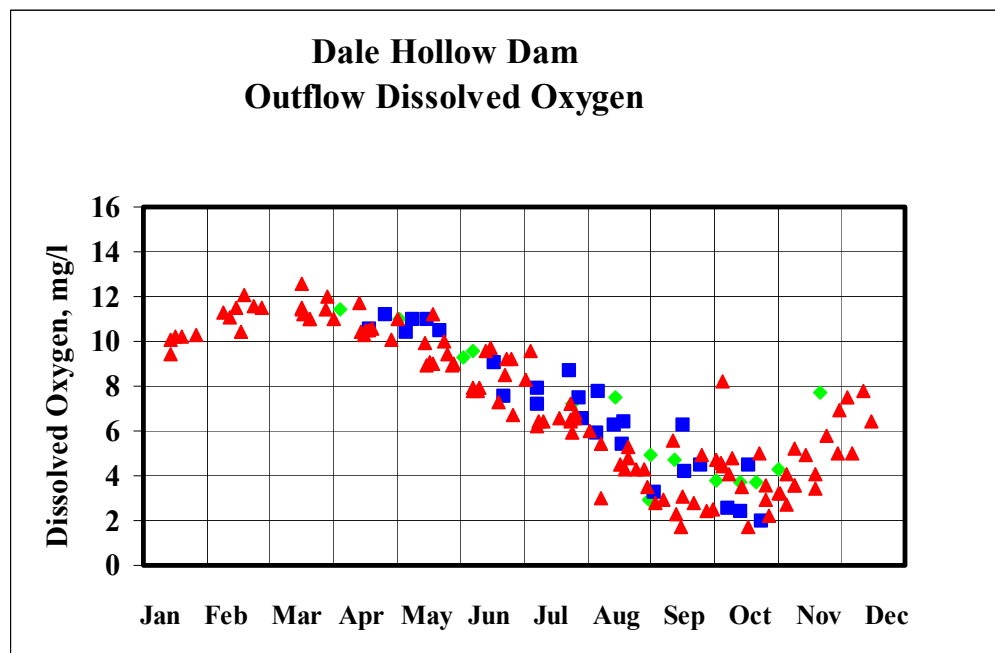


Figure 3. Dale Hollow Dam Outflow Dissolved Oxygen

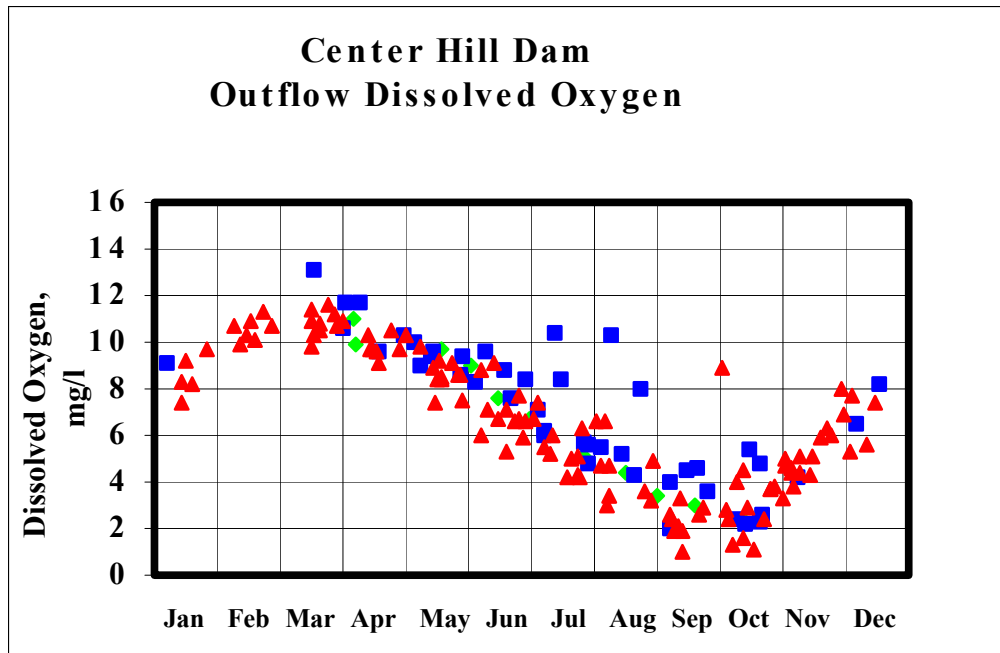


Figure 4. Center Hill Dam Outflow Dissolved Oxygen

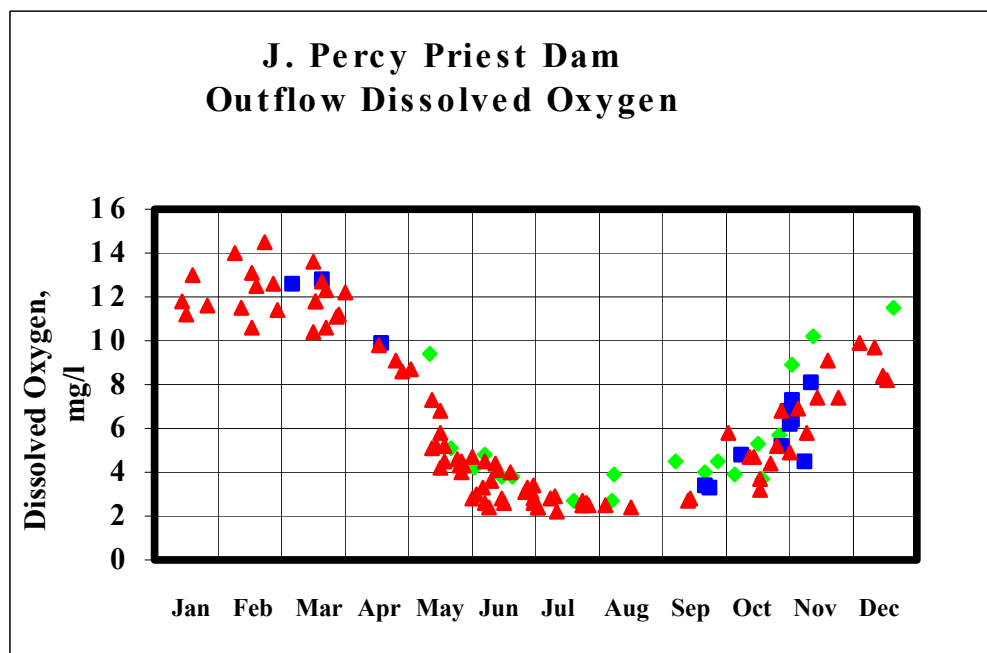


Figure 5. J. Percy Priest Dam Outflow Dissolved Oxygen

DO is the water quality parameter of primary concern related to activities at LRN dams. The water quality standard for DO is a minimum of 5.0 mg/l for a warmwater stream environment (Martins Fork, Cordell Hull, Old Hickory, J. Percy Priest,

Cheatham, and Barkley). The applicable standard for a coldwater environment capable of supporting a trout fishery (Laurel, Wolf Creek, Dale Hollow, and Center Hill) is an instantaneous minimum of 6.0 mg/l.

A review of the historical water quality database indicates that at one time or another all ten Cumberland Basin projects have violated the pertinent DO standard.

However, violations at some projects are so infrequent, difficult to anticipate, and of insignificant magnitude that physical modifications to these projects are not feasible.

Currently, low DO levels are more of a concern at the storage (tributary) projects than those located along the Cumberland River main stem. This hasn't always been the case. Prior to the development and implementation of the Cumberland Basin Reservoir System Model for Water Quality Control (CUBS), violation of the DO standard along the Cumberland River was not all that uncommon. Now, through the application of this tool, low DO events are anticipated allowing the appropriate water control measures to be implemented. The Old Hickory tailwater has long been recognized as the critical DO point along the Cumberland River main stem.

Currently, when DO violations are observed below Old Hickory, they are significantly reduced both in terms of magnitude and duration when compared to conditions prior to development of the CUBS model. In fact, during the past decade DO violations have only been observed in about half of those years and generally persisted for only a day or two. Thus, through the utilization of available water management tools, the reservoir system can be operated to prevent any DO violations (under most conditions) along the navigable reach extending from Celina, TN through the Cordell Hull, Old Hickory, Cheatham, and Barkley projects to the river's mouth at Smithland, KY.

The tributary storage projects are another story. Specifically, Wolf Creek (Lake Cumberland), Dale Hollow, Center Hill, and J. Percy Priest all have severe DO problems. Unlike the main stem projects where operational changes facilitated DO improvements, the tributary projects require physical modifications. DO depletion is more severe in tributary storage projects due to the manner in which they are operated. Water tends to pass through a main stem navigation project in a matter of a few days. However, the observed retention time for a tributary project is measured in months and in some cases exceeds one year. See Table 1 for a listing of average hydraulic retention times for the Cumberland Basin projects. Therefore, the natural processes responsible for DO depletion within the water column have more time to develop resulting in a higher degree of DO depletion and ultimately lower release DO concentrations.

Minimum Flow. The ability of hydropower to respond quickly to peak power demands makes it a very important component of the power production and distribution network. It is this peaking nature of hydropower operations that results in detrimental impacts to the downstream tailwater environment through daily wetting and drying of significant portions of the benthic habitat and subjecting benthic and fish populations to a repeated cycle of thermal shock. Benthic macroinvertebrates, the food base for the trout population, that are able to survive in

this cold-water environment are thus limited by the dewatering of the streambed. The current minimum flow criteria for LRN tributary projects are not sufficient to maintain a suitable wetted perimeter for benthic development in the upstream reaches of these tailwaters or to provide enough volume of cold water to meet temperature requirements in the lower reaches.

Turbine Venting

Turbine venting is generally the most cost-effective means of augmenting the DO concentration in releases made from hydropower facilities, and as such is a good first step in the process. It is a simple, low cost action that increases the amount of air introduced to the turbine and results in significant improvement to the downstream DO concentration. Turbine venting is site specific in nature and requires a detailed engineering analysis prior to implementation. Physical modifications required to implement turbine venting consist of the installation of hub baffles on the thrust relief ports and/or modification to the air supply system. See Figures 6 and 7. The baffles, which are typically fabricated out of stainless steel plate or piping, create a zone of negative pressure that results in more air being pulled into the unit (turbine). Air supply modifications may consist of relatively simple modification of the existing system or the installation of additional piping. The sole intent is to provide more air to the unit. Turbine venting is passive in nature. It is inexpensive to install and results in a relatively small efficiency loss. TVA's experience with turbine venting at several of their plants has indicated that efficiency losses in the range of 0.5-2.0 % can be expected.

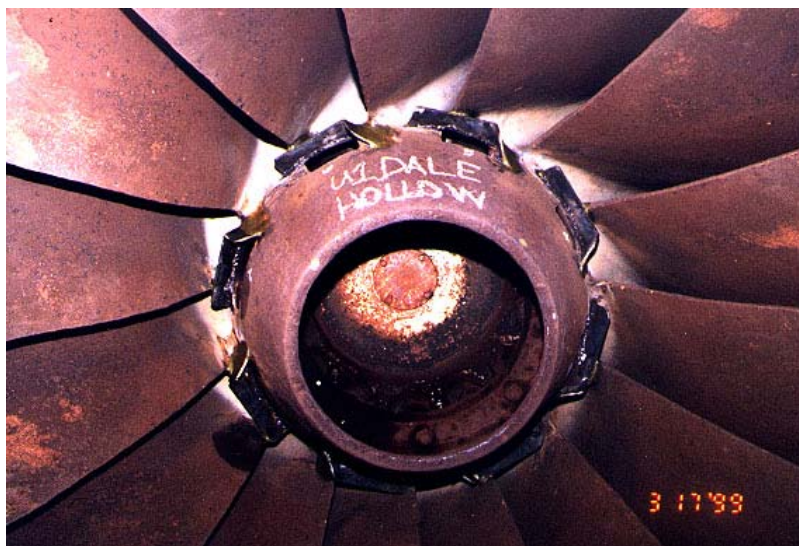


Figure 6. Hub Baffles Installed on Dale Hollow Unit #1



Figure 7. Vacuum Breaker Modifications Made to Center Hill Unit #3

Center Hill Dam. The LRN DO restoration effort began in September 1998 when hub baffles were installed on Center Hill Unit #3. This unit was carefully monitored over the next two years for any signs of cavitation or other damage resulting from the installation of hub baffles. The unit was dewatered at 6-month intervals to allow for a thorough inspection of the turbine runner. These inspections did not identify a significant amount of cavitation attributed to operating the unit with hub baffles in place. Therefore, approval was given to proceed with completing the air bypass modification to Unit #3. The vacuum breaker bypass air supply work was completed in September 1999. In September 1999, a post-modification engineering evaluation was completed on Unit #3. Data for several parameters including air flow, DO, headcover pressure, turbine efficiency, turbine shaft deflection, and turbine bearing temperature from the post-test, performed during the critical low DO season, were compared to similar measurements obtained prior to modification of the unit. Units #1 and #2 were assessed, modified, and evaluated in a similar fashion. Center Hill Power House electrical and mechanical staff, with assistance from TVA Engineering Laboratory personnel, completed the modifications to these two remaining units in July 2001. Post-modification tests were completed in September 2001 to verify anticipated DO improvements and to document turbine performance.

Post-modification testing at Center Hill identified a DO improvement of 2.5 mg/l for a single unit operating at 45 MW (nameplate capacity). At 10 MW the DO improvement for a single unit reached 3.5 mg/l. DO improvement fell off sharply to about 0.5 mg/l when two or three units were in operation. The tailwater elevation increases significantly under these flow conditions resulting in a loss of head required to pull air into the turbine. The efficiency loss, with units operated at 45 MW, was measured to be about 0.3 percent for all three units. Unit #3 actually exhibited a 0.2 percent efficiency increase during single unit use.

Dale Hollow Dam. Turbine venting modifications and associated engineering evaluations have been completed on all three 18 MW units at Dale Hollow. Unit #1 was modified in September 1999 followed by Unit #3 in March 2000 and Unit #2 in May 2000. Post-modification testing completed in September 1999 and September 2000 identified a single unit DO increase of around 2.0 mg/l at the seasonal power level of 15 MW. The DO improvement is more in the range of 0.5 – 1.0 mg/l for two and three unit use. Unit #2 was found to aspirate more air than the other two units. It is not readily apparent what is causing this disparity as similar modifications were made to each of the units and there are no obvious differences between units or in the channel geometry associated with their respective intakes. See Figure 8 for an overhead view of hydropower releases with and without turbine venting modifications.



Figure 8. Overhead View of Discharge at Dale Hollow Dam from Unit #1 (modified – left) and Unit #3 (prior to modification – right)

Wolf Creek Dam. Three of the six 45 MW hydropower units at the Wolf Creek Power Plant have had turbine venting modifications completed. In September 2000 LRN hydropower staff members installed hub baffles and a supplemental air supply system on Unit #1. This was followed in August 2001 with similar modifications to Unit #3 and Unit #5. The DO improvement for single unit operation was found to be around 2.5 mg/l. When multiple units are in operation the DO uptake decreases proportionally to the reduction in available head. The efficiency loss due to the introduction of additional air and the drag created by the presence of the baffles was documented to be 0.3 percent. No adverse effects were observed with regard to shaft deflection or turbine bearing temperature. See Figure 9 for an overhead view of the discharge from Wolf Creek Unit #3 before and after modification.

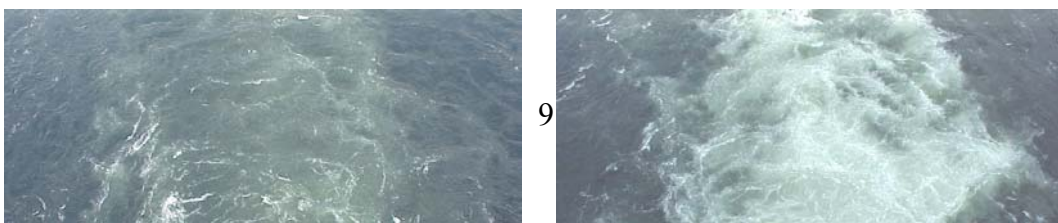


Figure 9. Overhead View of the Discharge from Wolf Creek Unit #3 Before (left) and After (right) Turbine Venting Modifications

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